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U. S. Army Research Laboratory Microelectromechanical System Electronically Scanned Antenna Testing at the Aviation and Missile Research, Development and Engineering Center

by Ronald G. Polcawich, Daniel Judy, Jeff Pulskamp
Steve Weiss, Janice Rock, and Tracy Hudson

ARL-TR-4359 **January 2008**

NOTICES

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14. ABSTRACT

Microelectromechanical System (MEMS) phase shifters have been assembled in a connectorized packages for insertion in a 1x8 linear patch antenna array. The patch array provides a demonstration platform for a MEMS enabled electronically scanned antenna (ESA). The MEMS ESA along with control electronics was tested in receive mode within anechoic chambers at both ARL and Aviation and Missile Research, Development and Engineering Center (AMRDEC). Using a waveguide horn antenna for the emission source, the ESA was steered with an electronically rotating stage. In each of the test sessions, the ESA successfully demonstrated beam steering to each of the five possible beam positions using 2-bit MEMS phase shifters.

15. SUBJECT TERMS
MEMS, RF switch, ESA, electronically scanned antenna

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1. Introduction

In continued support of the Consolidated Missile Seeker Army Technology Objective (ATO) Technology, Phased Arrays for Tactical Seekers (PATS) section, an 8-element, Ku-band Microelectromechanical System- (MEMS based subarray developed at the U.S. Army Research Laboratory (ARL) was evaluated in the RF Technology Division of the Aviation and Missile Research, Development, and Engineering Center (AMRDEC). The PATS portion of the ATO was a joint ATO between the AMRDEC and U.S. Army Research Laboratory (ARL). The purpose of the ATO was to study alternative designs for low-cost, low-loss phased array systems for tactical seeker systems.

The MEMS array consisted of eight elements, each element assigned to a 2-bit Ku-band, MEMS-based phase shifter. RF MEMS switch components were used in the construction of the phase shifters with an overall purpose of providing a low-cost, ultra low-loss phase delay to allow electronic steering of the radiation pattern. In addition, MEMS-based phase shifters present an opportunity for greater cost savings by reducing the number of transmit/receive (T/R) modules needed in an active array system. In current active array designs, the low noise amplifier (LNA) is located immediately adjacent to the radiating element, hereby amplifying the received signal at the earliest point while adding very little noise as shown in some of the current design configurations in figures 1 and 2.

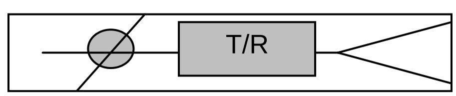


Figure 1. A single T/R module per radiating element, single phase network located away from the radiating element.

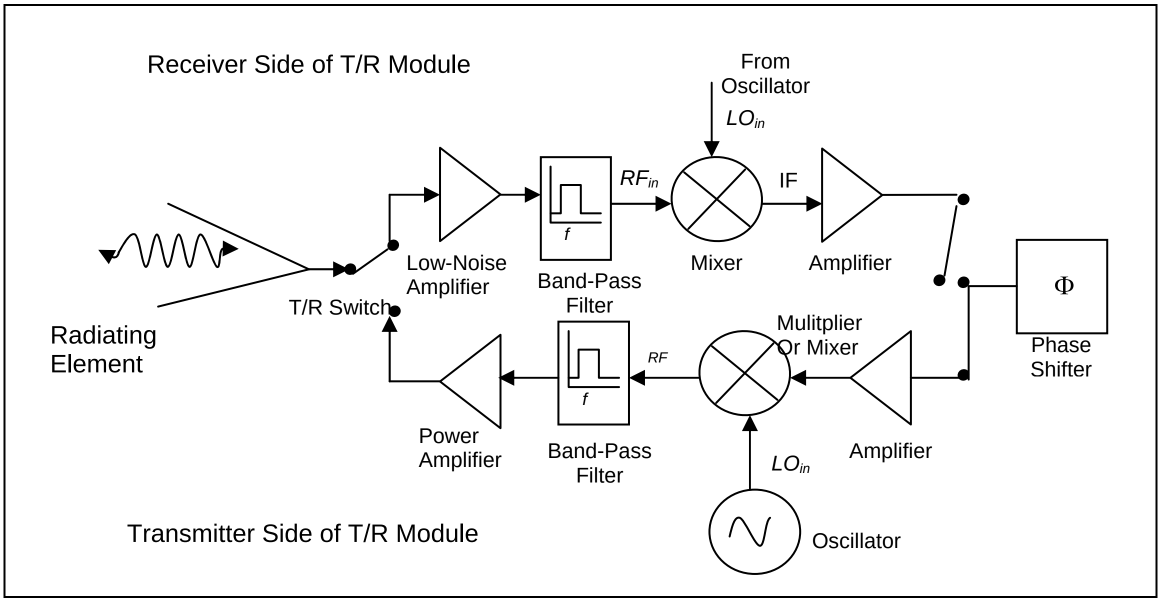


Figure 2. The components of a T/R module with multiple integrated phase networks.

Because MEMS-based phase shifters are low-loss devices, it is believed that MEMS will create an opportunity to locate a phasing network between the radiating element and the LNA. This will increase the potential cost savings of MEMS by allowing designs in which one T/R module feeds several radiating elements. Current T/R modules, particularly Pseudomorphic High Electron Mobility Transistor (PHEMT) designs, are capable of operation at voltages exceeding 10 V, thereby allowing the component to produce the necessary power to drive multiple radiating elements as shown in figure 3.

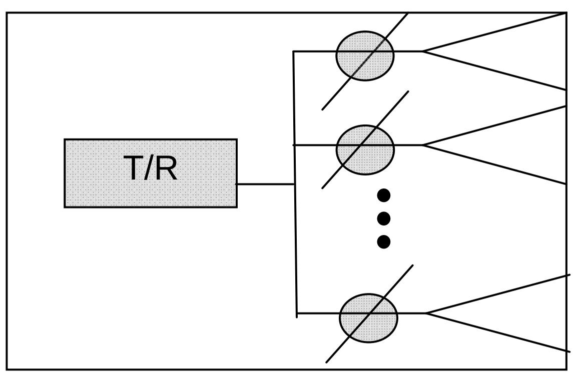


Figure 3. Possible design with low-loss phase network in which one T/R module feeds several radiating elements.

A MEMS electronically scanned antenna (ESA) allows for the elimination of the mechanical gimbal, thereby reducing the size, weight, and overall cost of the antenna in missile seeker applications. In an expendable device such as a missile seeker system, it is increasingly necessary to reduce cost while maintaining overall high performance levels. T/R modules are a large part of the overall cost in a phased array system, due to their highly fabrication intensive substrates. A reduction in the number of necessary T/R modules will greatly impact the overall cost of the system, and the small loss associated with the location of the phasing network can be overcome through engineering trades in performance enhancements.

This report describes the evaluation process and results for the testing of the ARL RF MEMS-based subarray. The subarray with MEMS-based phase shifters was evaluated to determine if the phase shifters are suitable for supplying the phase shift needed in each radiator of an antenna array to electronically steer the antenna beam.

2. Experimental Procedure

The performance of the RF MEMS switches and phase shifters and the packaging process for placing the phase shifters into connectorized RF packages has been outlined previously.[1,2] The patch antenna array in figure 4 consists of an RF input port, sections of microstrip with splitters to each of the eight phase shifters, and each of the eight slot fed patch antennas.

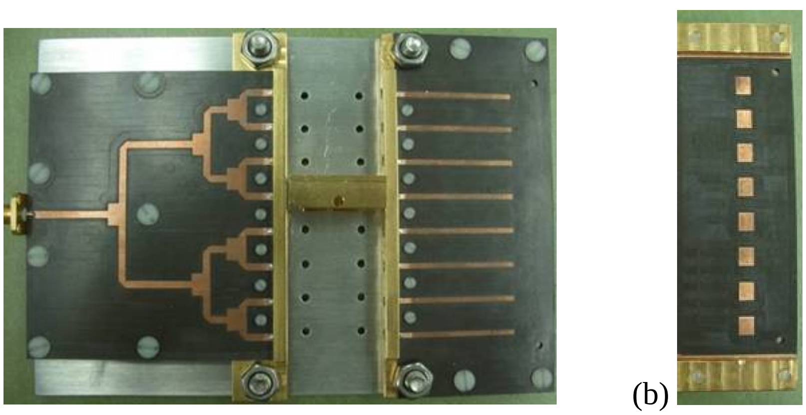
(a) (b)


Figure 4. The patch antenna array.

NOTE:

(a) Back view linear patch antenna array with microstrip transmission lines on a duroid substrate, a section for the 8 phase shifters.

(b) Front view) 8-slot fed patch antennas.

[1] Judy, D.; Pulskamp, J.; Polcawich, R.; Weiss, S. Demonstration of a Ku-band RF MEMS Enabled Electronically Scanned Antenna submitted to the Proceedings. *GOMAC* 2006.

[2] Polcawich, R.; Judy, D.; Pulskamp, J.; Weiss, S. *Ku-band RF MEMS Enabled Electronically Scanned Antenna*; ARL-TR-4280; Please provide the location of the conference. U.S. Army Research Laboratory: Adelpi, MD, 2007.

The assembled MEMS electronically scanned antenna ESA was prepared for testing by completing the wiring of each of the direct current (DC) control lines to the phase shifter control panel (see figure 5). The control panel has rotary switches to choose one of the four available phase states along with resistors and capacitors soldered to each of the switch locations to reduce any transient signals during the phase state selection process. The input to the phase shifter control panel consisted of two wires connected to a DC power supply.

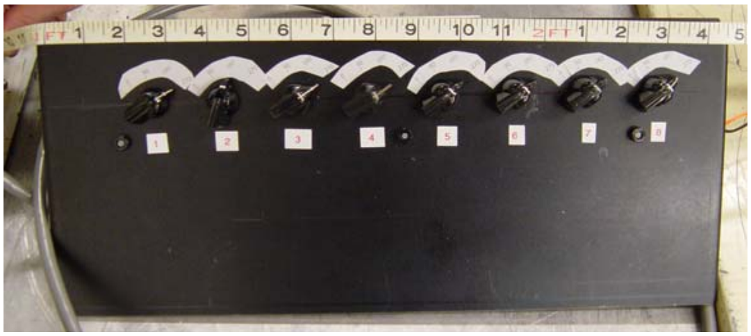


Figure 5. Phase shifter control panel consisting of rotary switches for each of the phase shifters.

Testing of the MEMS ESA occurred in anechoic chambers at the Harry Diamond Building at ARL (April 5, 2006 and April 20, 2006) and at the McMorrow Laboratory at AMRDEC (April 11, 2006). All testing was performed with the MEMS ESA in receive mode with a waveguide horn antenna specified for operating from 15 to 22 GHz. The ESA was held in position using a clamping circuit board holder and tape (figure 6).

(a) (b)

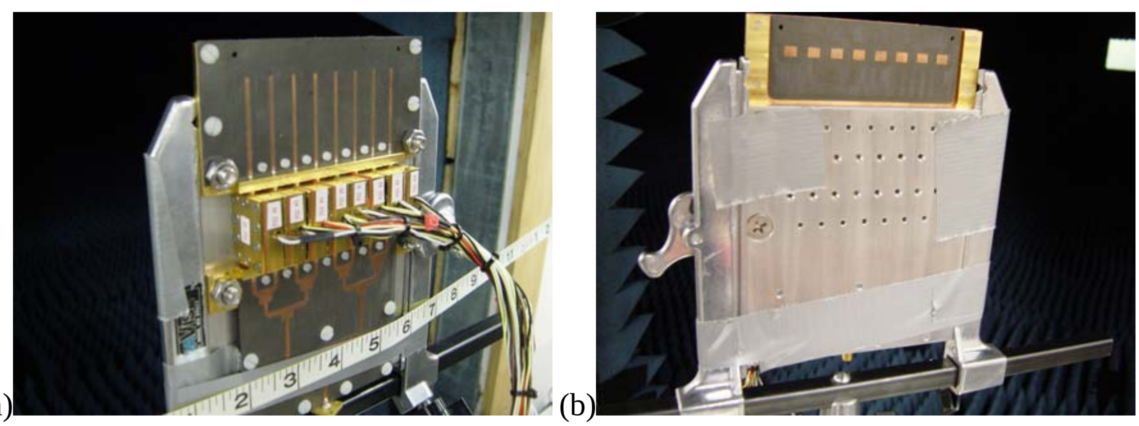


Figure 6. Mounted and fixtured MEMS ESA with clamping circuit board holder and tape keeping the antenna position fixed.

NOTE:
(a) backside view
(b) front view

At ARL, the transmit horn antenna was supplied RF energy with a Wiltron 68347B signal generator while the MEMS ESA was positioned approximately 50 feet from the horn. At AMRDEC, the horn antenna and the MEMS ESA were both connected to an Agilent N5230A PNA-L network analyzer with the ESA positioned 24 feet from the horn (figure 7). For each test, the ESA was attached to a computer-controlled rotary stage with adhesive tape (see figure 8).

Figure 7. Horn antenna connected to Agilent PNA-L network analyzer at far end of AMRDEC's anechoic chamber.

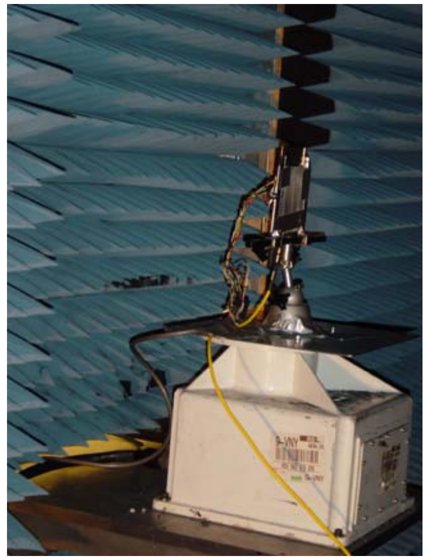


Figure 8. MEMS ESA attached to rotary stage within anechoic chamber at AMRDEC.

For tests at ARL, output from the detector and the stage controller was captured via a LabVIEW*-generated program and stored at either 0.5° or 1.0° increments from -90° to 90° at 15, 16, and 17 GHz. For testing at AMRDEC, individual s-parameter data was recorded from 15 to 20 GHz at 5° increments from -60° to 60°. A total of five tests were performed thereby examining each state of the MEMS array. The configuration of the phase shifters for each state is outlined in table 1.

Table. Description of ESA states.

State	Delta Phi (Δφ)	Position of 1st Phase Shifter
0	0º	0º
0	0º	270º[a]
1	90º	0º
2	-90º	270º
3	180º	0º
4	-180º	180º

[a] All MEMS switches off

* LabVIEW is a product of National Instruments and is an intuitive graphical programming language.

3. Results and Discussions

The ESA results at 17 GHz recorded at ARL on April 5, 2006 agree with the results reported earlier and can be seen in figure 9. (*1*, *2*) Again, approximately 25° of beam steering was achievable between states 0, 1, and 2. Since the AMRDEC laboratory setup was manual and very time consuming, data for the AMRDEC evaluation was collected in 5° increments, creating a relatively coarse plot. Data was collected for a frequency band of 15 to 20 GHz to determine the bandwidth of the subarray. The antenna performed relatively well across the frequency range.

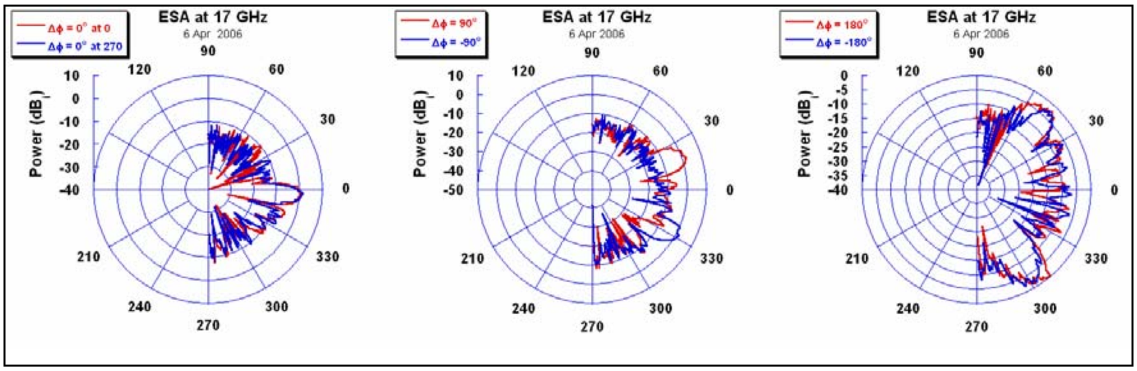


Figure 9. ESA test results at ARL on April 5, 2006.

Figure 10 shows the data collected for states 0, 1, 2, and 3 for 15, 16, and 17 GHz. Similar to results from ARL, approximately 25° of beam steering was achievable at all frequencies examined.

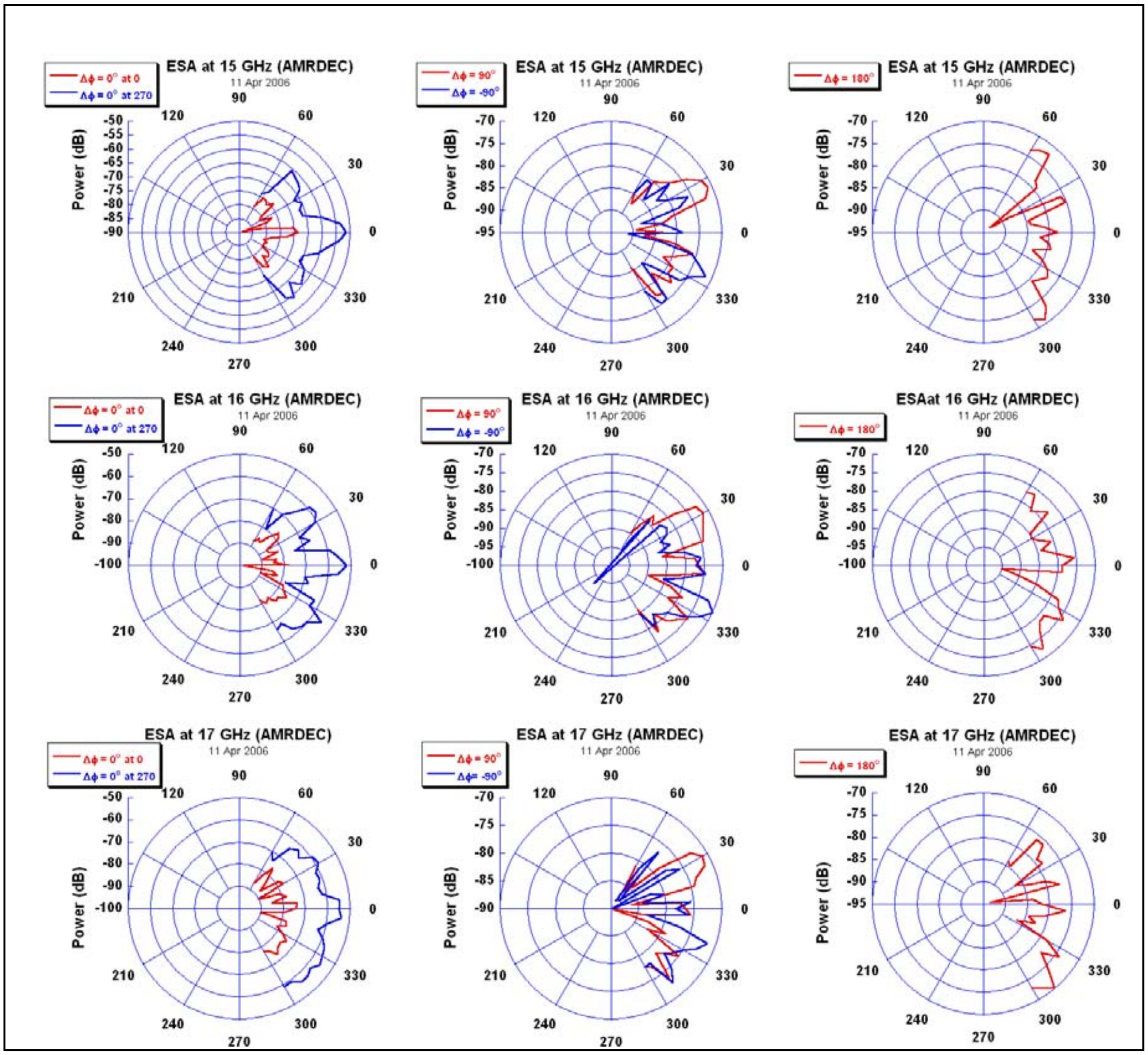


Figure 10. ESA test results at AMRDEC.

Upon returning to ARL, the MEMS-enabled ESA was tested in the ARL's anechoic chamber with data collected at 15, 16, and 17 GHz with a better angular resolution. The data illustrated in figure 11 was similar to that obtained at AMRDEC except with finer resolution. Additionally, this data was normalized using a standard gain horn which revealed a gain of approximately 5 to 7 dB at the design frequency of 17 GHz.

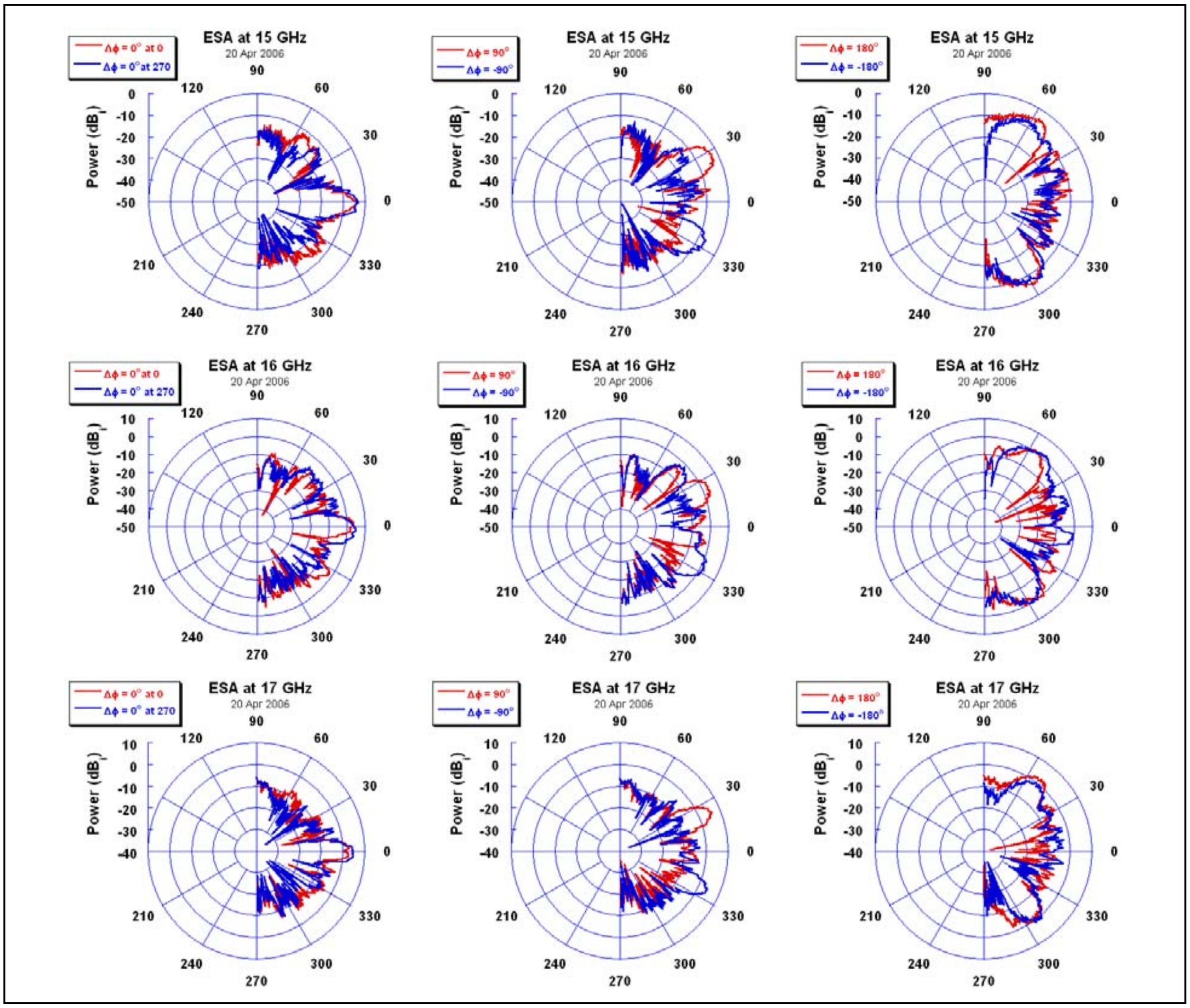


Figure 11. ESA test results at ARL on April 20, 2006.

4. Conclusion

The results obtained at AMRDEC are comparable to the results obtained at ARL; small discrepancies could be explained by differences in test equipment. The laboratory evaluation is considered a success and shows that MEMS-based phasing networks can be used to provide the necessary phase shift needed to direct a radiated energy source to a desired steering angle.

The performance of MEMS-based phase shifters is encouraging and their potential benefits are many. Even though this current design does not meet the PATS requirement for loss, the overall losses are already much lower than traditional commercial-off-the-shelf (COTS) phase shifter elements and some designs have been at or near the requirement. Future effort will be directed to reducing loss in the phase shifters as well as the packaging of the phase shifting elements and developing a 3-bit ESA for similar testing.

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Acronyms

AMRDEC	Aviation and Missile Research, Development and Engineering Center
ARL	U.S. Army Research Laboratory
ATO	Army Technology Objective
COTS	commercial-off-the-shelf
DC	direct current
ESA	electronically scanned antenna
LNA	low noise amplifier
MEMS	Microelectromechanical System Electronically Scanned
PATS	Phased Arrays for Tactical Seekers
PHEMT	Pseudomorphic High Electron Mobility Transistor
RF	radio frequency
T/R	transmit/receive

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